Sensor Networks and Configuration
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Sensor Networks and Configuration

Fundamentals, Standards, Platforms, and Applications

Springer
Dedicated to my

Teachers and family members
Preface

Advances in networking principles may indeed influence many kinds of monitoring and control systems in the most dramatic way. Sensor network and configuration (SNC) falls under the category of modern networking systems. A Wireless Sensor Network (WSN), a sophisticated, compact, and advanced networking method has emerged that caters to the need for real-world applications. Methodology and design of WSNs represent a broad research topic with applications in many sectors such as industry, home, computing, agriculture, environment, and so on, based on the adoption of fundamental principles, specifications characterisations, modeling, simulations, and state-of-the-art technology. Technological research in this field is now expanding; its design phases appear to be highly complex and involve interdisciplinary approaches.

The main objective of this book is to provide information on concepts, principles, characteristics, applications, latest technological developments, and comparisons with regard to sensor networks and configuration. This book incorporates research, development, tutorials, and case studies. Academic and industrial research and developments in networked monitoring and control (e.g., intelligent home, pet management, etc.) are being carried out at many different institutions around the world. The technological trends in this domain (e.g., design, integration, communication schemes, development methodology, current application scenarios, pros and cons, etc.) need to be extensively disseminated so that the sensor network revolution can spread to serve society in a bigger way. In particular, the book is intended to focus on describing the implicit concept of advanced networking, personal area networking, and mobile area networking, as well as application-oriented design tips and hints, as much as the techniques and methodology. This book will enable readers to understand the underlying technology, philosophy, concepts, ideas, and principles, with regard to broader areas of sensor networks. Aspects of sensor network in terms of basics, standardization, design process, practice, techniques, platforms, and experimental results have been presented in a proper order. Fundamental methods, initiatives, significant research results, as well as references for further study have also been provided. Relative merits and demerits are described at the appropriate places so that novices as well as advanced practitioners can use the evaluation to guide their choices. All the contributions have been reviewed, edited, processed and placed in appropriate order to maintain consistency so that irrespective of whether the reader is an advanced practitioner or a newcomer he or she can get most out of it. Since this book covers many aspects of SNC the importance of this order is considered significant. The roadmap of the book is as follows.

Chapter 1 is a general introduction. Chapter 2 presents the backbone of WSNs, the IEEE 802.15.4 protocol. The requirements for service-oriented sensor webs are presented in Chapter 3. Cross-layer design principles are described in Chapter 4. Grid computing has evolved as a standards-based approach for coordinated resource sharing. There are several issues and challenges in the design of sensor
grids. Chapter 5 has been dedicated to the sensor grid architecture for distributed events classification. Chapters 6, 7, and 8 deal with topology controls, routing protocols, and energy aware routing fundamentals, respectively. Chapter 9 discusses the aspects of probabilistic queries and quality assurances. A statistical approach based resilient aggregation is studied in Chapter 10. The communication performance study is presented in Chapter 11. A sensor network consists of a large number of nodes connected through a multi-hop wireless network. Data management is an issue discussed in Chapter 12. Localisation and location estimation are also two important design considerations. Chapters 13 and 14 introduce these. It has been variously proposed that the future of the monitoring and control will be based on sensor networks. A comprehensive description of an application driven design, ZigBee WSN and their applications, MANET versus WSN, etc. can be found in Chapters 15-17. There has been recent confusion on sensor network and industrial Distributed Control Systems (DCS). In fact, sensor networks and DCS are complementary to each other. As such, two chapters have been dedicated to introduce industrial sensor and actuator networks; (the fieldbus) and the DCS simulation scenario. The book also contains three chapters regarding applications of WSNs. The application domains are pet management systems, agriculture monitoring, and intelligent CCTV. The last supplemental chapter reviews the modulation techniques and topology, an essential topic for novice researchers and readers.

The success story of this book ‘Sensor Network and Configuration’ is due to the direct and indirect involvement of many researchers, technocrats, academicians, developers, integrators, designers, and last but not the least the well-wishers. Therefore, the editor and hence the publisher acknowledge the potential authors and companies whose papers, reports, articles, notes, study materials and websites have been referred to in this book. Further, many of the authors of the respective chapters gracefully acknowledge their funding agencies, without which their research could not have been completed. Every precaution has been taken to credit their work in terms of citing their names and copyright notices under the figures and texts incorporated in this book: but in case of error we would like to receive feedback so that the same can be incorporated in the next phase of printing.

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1 Introduction

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1.1 Introduction and Background

A sensor network is a network of many smart devices, called nodes, which are spatially distributed in order to perform an application-oriented global task. The primary component of the network is the sensor, essential for monitoring real-world physical conditions or variables such as temperature, humidity, presence (absence), sound, intensity, vibration, pressure, motion, and pollutants, among others, at different locations. Each smart device within the network is small and inexpensive, so that it can be manufactured and deployed in large quantities. The important design and implementation requirements of a typical sensor network are energy efficiency, memory capacity, computational speed and bandwidth. The smart device has a microcontroller, a radio transceiver, and an energy source. Sometimes a central computer is integrated onto the network in order to manage the entire networked system. Regardless of achieving its global task, a sensor network essentially performs three basic functions: sensing, communicating and computation by using the three fundamental components: hardware, software and algorithms, respectively.

Conventionally, a sensor network is considered a wireless network, however, some sensor networks are wired or hybrid types. For example, fieldbus-type systems (Mahalik 2003) are usually wired networks (optical fibers, co-axial cables, etc. are used). A wireless sensor network (WSN), as its name implies, consists of a number of microcontroller-integrated smart devices. Each node is equipped with a variety of sensors, such as acoustic, seismic, infrared, still/motion video-camera, and so on. The node has some degree of intelligence for signal processing and management of network data.

The basic goals of a WSN are to: (i) determine the value of physical variables at a given location, (ii) detect the occurrence of events of interest, and estimate parameters of the detected event or events, (iii) classify a detected object, and (iv) track an object (w3.antd.nist.gov). Thus, the important requirements of a WSN are: (i) use of a large number of sensors, (ii) attachment of stationary sensors, (iii) low energy consumption, (iv) self-organisation capability, (v) collaborative signal processing, and (vi) querying ability.
Fig. 1.1 shows the general architecture of a sensor network. As can be seen in the figure, the three important layers are the services-layer, data-layer, and physical-layer. The layers provide routing protocol, data dissemination, and aggregation. The physical-layer containing the node defines itself as either a sink node, children node, cluster head, or parent node. Parent nodes are integrated to more than two cluster heads. Messages are modeled in the data-link layer. Broadcasting of a query is carried out by the use of sink nodes. The broadcasting can be either to the sensor network or to a designated region depending on the way the query is being used. In response to a change in the physical parameter the sensor nodes, which are close to the sensed object, broadcast this information to their neighbouring sensor nodes. In effect, a cluster head will receive this transmission. The role of a cluster head is to process and aggregate this data and broadcast it to the sink node(s) through the neighboring nodes. This is due to the fact that cluster head receives many data packets from its children (Tubaishat M. and Madria).

Some of the important application domains of WSNs are listed below.

- Military sensor networks
- Networks for detecting chemical, biological, radiological, nuclear, and explosive material
- Environmental monitoring networks
- Traffic sensor networks
- Surveillance applications
- Parking systems in shopping malls and big markets

A more comprehensive list of the research and development areas of WSNs is given below.

- Adaptive beacon placement
• Adaptive protocols (Kulik et al. 1999) for information dissemination
• Adaptive self-configuring topologies
• Address-free architecture for dynamic networks
• Addressing mechanisms
• Application specific protocol architectures
• Data gathering using energy delay metric
• Data-centric storage
• Directed diffusion-scalable communication paradigm
• Distributed micro-sensor systems
• Dynamic fine-grained localisation
• Dynamic power management
• Energy complexity, energy-efficient MAC (Media Access Control)
• GPS-less outdoor localisation for very small devices
• Habitat monitoring
• Impact of network density on data aggregation
• Instrumentation
• Location mechanisms
• Low-, ultra-low power systems, low power systems-on-a-chip
• Low-level naming
• Mobile networking for Smart Dust
• Modeling and simulation
• Negotiation-based protocols for disseminating information
• Network interfaces for hand-held devices
• Network layers
• Physical layer driven protocol
• PicoRadio
• Positioning system, convex position estimation
• Prediction-based monitoring
• Probabilistic approach to predict energy consumption
• Protocols for self-organisation
• Random, ephemeral transaction identifiers
• Recursive data dissemination
• Residual energy scans for monitoring
• Routing, Rumor routing algorithm
• Scalable computation, scalable coordination
• Self-configuring localisation systems
• Service differentiation
• System architecture directions
• Time synchronisation
• Topology discovery algorithm
• Transmission control for media access
• Upper bounds on the lifetime of WSNs
The main objective of this book is to provide information on concepts, principles, characteristics, applications, latest technological developments, and comparisons with regard to WSNs and their configuration. It incorporates current research, development, and case studies. Academic and industrial research and developments in WSNs are being carried out at many different institutions around the world. The technological trends in this domain (e.g., design and development methodology, current application scenarios, pros and cons, etc.) need to be extensively disseminated so that the revolution can spread to serve society. This book is intended to focus on describing the implicit concepts, multi-engineering principles of networking systems, state-of-the-art tools, design tips and hints, rather than solely focusing on techniques and methodology. In particular, the scope of the book, which will be briefly presented in the sequel, is as follows.

- Modulation techniques
- IEEE 802.15.4 and ZigBee protocols
- Cross layer design
- Sensor-grid computing architecture
- Topology control
- Routing protocols and energy aware routing
- Quality assurance
- Aggregation
- Communication performance
- Sensor data management
- Localisation and estimation
- SensorWeb
- Distributed controls
- Applications: pet-dog management, agricultural monitoring, and CCTV

1.2 IEEE 802.15.4

WSNs have been attracting increasing interest for developing a new generation of embedded systems. Communication paradigms in WSNs differ from those associated to traditional wireless networks, triggering the need for new communication protocols. In this context, the recently standardised IEEE 802.15.4 protocol presents some potentially interesting features, such as power-efficiency, timeliness guarantees, and scalability. When addressing WSN applications with timing requirements (soft/hard) some inherent paradoxes emerge, such as power-efficiency versus timeliness, and scalability versus communication latencies, triggering the need of engineering solutions for the efficient deployment of IEEE 802.15.4 in WSNs. This book includes the most relevant characteristics of the IEEE 802.15.4 protocol for WSNs and presents important research challenges for time-sensitive applications. Timeliness analysis of IEEE 802.15.4 will unveil relevant directions for resolving the paradoxes mentioned above. IEEE 802.15.4 is a standard defined...
by the IEEE (Institute of Electrical and Electronics Engineer) for low-rate, wireless personal area networks (PAN). It defines both physical and medium access layers. The physical layer and media access layers are called PHY and MAC, respectively, and the former defines a low-power spread spectrum radio operating at 2.4 GHz with a fundamental bit rate of 250 kbs. There is also an alternate PHY specification, which works around 915 MHz and 868 MHz for operating at lower data rates. The MAC specification deals with the multiple radio operation. It supports several architectures such as tree topologies, star topology, and mesh topologies as shown in the Fig. 1.2.

Fig. 1.2. Some of the typical IEEE 802.15.4 topologies (Source: http://en.wikipedia.org)

1.3 ZigBee

The ZigBee alliance, incorporated in August 2002, is an association of companies working together to enable reliable, cost-effective, low-power, wirelessly networked, monitoring and control products based on an open global standard. Many research institutes and industrial companies have developed sensor platforms based on ZigBee and IEEE 802.15.4 solutions. The ZigBee alliance includes leading semiconductor manufacturers, technology providers, OEMs, and end-users worldwide. Membership in the alliance is approaching 200 companies in 24 countries. The objective of this organisation is to provide the upper layers of the protocol stack, essentially from the network to the application layer, including application profiles. It also provides interoperability compliance testing, marketing of the standard, and advanced engineering for the evolution of the standard (http://www.caba.org/standard/zwigbee.html).

ZigBee technology is suited for sensor and control applications, which do not require high data rates, but must have low power, low costs and ease of use in the platform, such as remote controls and home automation applications. One can note that ZigBee builds upon the 802.15.4 standard to define application profiles (Fig. 1.3) that can be shared among different manufacturers. The origin of ZigBee comes from the fact that simply defining a PHY and a MAC does not guarantee that different field devices will be able to talk to each other. As already pointed out, ZigBee starts with the 802.15.4 standard, and then defines application profiles.
that can allow devices manufactured by different companies to talk to one another. ZigBee supports both star and mesh topologies. One chapter is dedicated to provide detail information on ZigBee. The chapter also discusses some applications such as medical care and fire emergency system along with some prototyping systems.

Fig. 1.3. ZigBee defined layers/specification (Courtesy: ZigBee Alliances)

1.4 Cross-layer Design

Continued study on cross-layer protocols, protocol improvements, and design methodologies for WSNs is important. A cross-layer design paradigm is necessary to achieve the desired performance of the transmission protocol stack in terms of meeting QoS (Quality of Service) (Macias 2003) requirements. Cross-layer protocol engineering is an emerging research area addressing relevant issues that support their needs. The development of concepts and technologies are critical. The protocols that focus on cross-layer design techniques are to be reviewed and classified. Methodologies for the design of cross-layer solution for sensor networks as resource allocation problems in the framework of non-linear optimisation are discussed in this book. Open research issues in the development of cross-layer design methodologies are also discussed and possible research directions are indicated. The shortcomings of design techniques such as lack of modularity, decreased robustness, difficulty in system enhancements, and risk of instability are discussed, and precautionary guidelines are presented. The research considerations are:

- Architectures and methodologies
- Exploitation of physical layer information for medium access control
- Management and congestion control
- Cross-layer adaptation for energy minimisation
- End-to-end QoS
- Simulation tools
- Scalability issues
- Signaling and interaction
1.5 Sensor-Grid Computing

Real-time information about phenomena in the physical world can be processed, modeled, correlated, and mined to permit ‘on-the-fly’ decisions and actions in a large-scale environment. Examples include surveillance for homeland security, business process optimisation, environment monitoring with prediction and early warning of natural disasters, and threat management (e.g. missile detection, tracking and interception). In one chapter, the sensor-grid computing concept, the SensorGrid architecture is described and the works on information fusion, event detection and classification, and distributed autonomous decision-making on SensorGrid, are presented as examples of what can be achieved. Integrating sensor networks and grid computing (Estrin et al. 2002) based on SensorGrid architecture is like giving ‘eyes’ and ‘ears’ to the computational grid.

1.6 Routing Protocol

Routing in WSN presents unique challenges as compared to traditional techniques in other conventional wired and wireless networks. This book dedicates a chapter, to outlining many design issues, and presents a number of state-of-the-art schemes that have been proposed during recent years. The approaches have been classified into flat, hierarchical and geographic routing based on the network structure for which they are proposed. The authors of this chapter have briefly discussed the schemes outlining the routing mechanism, both advantages and drawbacks. Although most of them are quite successful in fulfilling the requirements, there are still many challenges to overcome before WSN technology becomes mature.

1.7 Energy Efficiency

From on-going research work it has been deemed that there is a pressing demand to design new routing protocols for WSNs, since the features and applications of WSNs are substantially different from similar networks like wireless ad-hoc networks. Energy is a much more scarce resource in WSNs, and therefore all routing protocols designed for WSNs should consider the energy consumption as the primary objective to optimise. There are various energy efficient routing protocols proposed for WSNs. It is equally imperative to outline the differences between WSNs and wireless ad-hoc networks as far as routing is concerned. New approaches such as the cross layer design in the design of protocols for WSNs are also similarly important. The effect of link layer wireless technology on the design of routing protocols is considered in practical realisations of WSNs.

Energy-efficient data management for sensor networks is a challenging problem. Three topics, data storage, exact query processing, and approximate query processing, are to be the matter of discussion. The foremost design principle of an
energy-efficient sensor network is to combine pull- and push-based data dissemi-
nation schemes so as to strike a balance between the query arrival rate (and query
precision if it is an approximate query) and data capture rate. In other words, the
sensor networks should reduce the cost of sampling, storage and transmission of
unnecessary data, i.e., those data that do not affect the query result, as much as
possible. The various techniques discussed in that chapter will inspire the reader in
developing their own applications.

1.8 Topology Control

Energy saving by TC is identified to be one of the methods (Deb et al. 2002).
Analysis of sensor node lifetime shows a strong dependence on battery lifetime. In
a multi-hop ad-hoc WSN, each node plays the dual role of data originator and data
router. The malfunctioning of a few nodes can cause significant data loss due to
topological changes, and might require rerouting of packets and reorganisation of
the network. Hence, power conservation and power management take on addi-
tional importance. For these reasons, we need power-aware protocols and algo-
rithms for WSNs. In this book we have presented an overview of the topology
control (TC) problem in WSNs for both stationary and mobile types, and discuss
various solutions proposed to prolong the lifetime of WSNs by minimising energy
requirements. We have also classified various TC protocols, and analysed their
approaches. To this extent, a summary is provided in Table 1.1. As can be seen,
mmost practical TC problems are NP-hard or NP-complete. Hence, only approxi-
mate solutions exist for some specific problems. There still remain many open
problems for which no good heuristic exists. It is expected that research would be
carried on to improve upon existing heuristics, and to determine good approximate
algorithms for the harder open problems.

1.9 Quality Assurance

In a large network, sensors are often employed to continuously monitor changing
entities like locations of moving objects and temperature. These sensor readings
are usually used to answer user-specified queries. Due to continuous changes in
these values in conjunction with measurement errors, and limited resources (e.g.,
network bandwidth and battery power), the system may not be able to record the
actual values of the entities.

Queries that use these values may produce incorrect answers. However, if the
degree of uncertainty between the actual value and the database value is limited,
one can place more confidence in the answers to the queries. Answers to the query
can be augmented with probabilistic guarantees. This book has a chapter, which
deals with the quality assurance aspect of the sensor network. In particular, it em-
phasises how the quality of queries can be guaranteed for uncertain sensor data.
We discuss a classification scheme of queries based upon the nature of the result set, and how probabilistic answers can be computed for each class. This suggests the identification of different probability-based and entropy-based metrics for quantifying the quality of these queries.

Table 1.1: Comparison of TC protocols (Contributed by Debasis Saha)

<table>
<thead>
<tr>
<th>Topology Control Algorithm</th>
<th>Graph Model</th>
<th>Methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>MECN and SMECN</td>
<td>Minimum power topology di-graph, two-dimensional space.</td>
<td>Uses localised search and applies distributed Bellman-Ford algorithm.</td>
</tr>
<tr>
<td>Distributed Cone Based (CBTC)</td>
<td>Two-dimensional plane. Undirected graph</td>
<td>Builds a connected graph, followed by redundant edge removal.</td>
</tr>
<tr>
<td>LINT, LILT, CONNECT, Bicon-Augment</td>
<td>Undirected and directed</td>
<td>One algorithm is similar to minimum spanning tree and another to depth first search. LINT uses local while LILT global information for mobile networks.</td>
</tr>
<tr>
<td>Loyd et al.</td>
<td>Undirected and directed graphs with preferably monotone graph property.</td>
<td>Estimates total number of candidate optimal power values. For each value, constructs a directed graph followed by sorting and searching.</td>
</tr>
<tr>
<td>Krumke et al.</td>
<td>Undirected</td>
<td>Uses (MCTDC) (minimum cost tree with a diameter constraint); a combination of sort &amp; search; and an algorithm for Steiner Trees.</td>
</tr>
<tr>
<td>SMET protocols</td>
<td>Undirected</td>
<td>One heuristic is based on a minimum edge cost-spanning tree and the second one is an incremental power heuristic.</td>
</tr>
<tr>
<td>MobileGrid</td>
<td>N.A.</td>
<td>Estimates CI for each node, checks for optimal CI and adjusts transmit power based on this information.</td>
</tr>
<tr>
<td>COMPOW</td>
<td>N.A.</td>
<td>Maintains routing tables at all power levels, and then selects the optimum power level based on the routing information.</td>
</tr>
<tr>
<td>K-NEIGH</td>
<td>Undirected</td>
<td>Computes a symmetric sub-graph of the k nearest neighbours graph by ordering the list of k nearest neighbours.</td>
</tr>
<tr>
<td>CLTC</td>
<td>Undirected</td>
<td>Forms clusters and selects cluster heads followed by intra-cluster and inter-cluster TC.</td>
</tr>
<tr>
<td>Dist. NTC</td>
<td>Planar undirected graph with maximum triangulation</td>
<td>Determines topology using Delaunay Triangulation. Then it adjusts each node degree through neighbor negotiation so that each node has a similar number of neighbours.</td>
</tr>
</tbody>
</table>
pling uncertainty. The second method exploits the low-cost nature of sensors and selects an appropriate number of redundant sensors in order to alleviate the problem of noisy data. Both methods are aware of the limited resource of network bandwidth, and only pull data from sensors when necessary.

1.10 Aggregation

In typical sensor network applications, the sensors are left unattended for long periods of time. In addition, due to cost reasons, sensor nodes are not usually tamper resistant. Consequently, sensors can be easily captured and compromised by an adversary (e.g., bogus measurements). Once compromised, a sensor can send messages to other nodes and to the base station, but those messages may contain arbitrary data. A similar effect can be achieved by manipulating the physical environment of uncompromised sensors so that they measure false values. Bogus data introduced by the adversary may considerably distort the output of the aggregation function at the base station, and may lead to wrong decisions. The goal of resilient aggregation is to perform the aggregation correctly despite the possibility of the above mentioned attacks. A chapter in the book gives an overview of the state-of-the-art in resilient aggregation in sensor networks, and briefly summarises the relevant techniques in the field of mathematical statistics. An approach for resilient aggregation is subsequently introduced and discussed in more detail. This approach is based on RANSAC (RAndom SAmple Consensus). The authors have also presented some initial simulation results showing that a RANSAC-based approach can tolerate a high percentage of compromised nodes.

1.11 Localisation

Sensor network localisation is an important area that has recently attracted significant research interest. In a typical WSN many sensors work together to monitor conditions at different locations. Knowing the sensor location where data is sensed is important not only to interpret the data, but also to efficiently route data between nodes. Localisation of a node refers to the problem of identifying its spatial co-ordinates in some co-ordinate system. Many methods have been proposed for localisation. The most commonly used method is some variation of multilateration, which is an extension of trilateration. Trilateration techniques use beacons, which act as reference points for a node, to calculate its own position. Sufficient numbers of beacons are necessary as otherwise nodes, which are not aware of their positions, will not be able to calculate their positions. At the same time, too many beacons become expensive and cause self-interference. Thus, it is necessary to have optimal beacon placement. Most WSN applications require accurately measuring the locations of thousands of sensors. The three major categories of measurement techniques are:
1 Introduction

- Received signal strength measurements
- Angle of arrival measurements
- Propagation time based measurements

The localisation algorithms built on these measurement techniques are subsequently discussed.

In a WSN, which measurement technique and algorithm to use for location estimation will depend on the specific application. There are a number of factors that may affect the decision. These include cost, energy, localisation accuracy, efficiency and scalability of the algorithm. Some algorithms like the category of connectivity-based localisation algorithms, although not able to give an accurate location estimate, can be attractive for applications requiring an approximate location estimate only due to their simplicity. The fundamental theory underpinning distance-based sensor networks from the graph theory point of view is also presented. Two fundamental problems in the area are whether a specific sensor network with a given set of sensors and inter-sensor distance measurements is uniquely localisable, and the computational complexity of the localisation algorithm. Some important results in this area are introduced. Finally, some current researches on distance-based sensor network localisation are presented.

1.12 Sensor Web

The Sensor Web is an emerging trend (Fig. 1.4), which makes various types of web-resident sensors, instruments, image devices, and repositories of sensor data discoverable, accessible, and controllable via the World Wide Web (WWW). Sensor Web enables spatio-temporal understanding of an environment through coordinated efforts between (i) multiple numbers and types of sensing platforms, (ii) orbital and terrestrial, and (iii) both fixed and mobile. A lot of effort has been invested in order to overcome the obstacles associated with connecting and sharing the heterogeneous sensor resources. One chapter in this book emphasises the Sensor Web Enablement (SWE) standard defined by the OpenGIS Consortium (OGC), which is composed of a set of specifications, including SensorML, observation and measurement, sensor collection service, sensor planning service and web notification service. It also presents reusable, scalable (Intanagonwiwat et al. 2000), extensible, and interoperable service oriented sensor web architecture that:

- Conforms to the SWE standard
- Integrates Sensor Web with grid computing
- Provides middleware support for Sensor Webs
In addition, the chapter describes the experiments and an evaluation of the core services within the architecture.

Fig. 1.4. A glance at Sensor Web (Reichardt 2003; Copyright: Geospatial Solutions)

1.13 MANET versus WSNs

MANET has been expanded as a mobile ad-hoc network, a network that has self-configuration capability in terms of configuring networks of mobile routers and hosts (stations) interfaced with wireless links. The integrated system forms an arbitrary topology. In this network, the stations can move around and change the network topology. The wireless topology of the network can change rapidly and unpredictably. It is presumed that there exists a difference between MANET and the emerging WSNs. One chapter is dedicated to review and analyse the similarities as well as the differences, between MANET and WSNs. The main focus of discussion is on how they are (or not) alike. From certain points of view a WSN is seen as a special type of MANET; the protocols, algorithms, and design issues of the former cannot be applied to the latter.

Although, wireless ad-hoc networks have been studied for nearly three decades, there are still opportunities for research. Some of these opportunities may derive from the fact that most previous researches are around military applications and that the basic assumptions for these applications may not hold for common non-military applications. Some argue that it has just barely reached the end of its exploratory stage, where the foundations have been laid out, in practice it is a fact that WSNs have been used for applications with limited scope, or just as prototypes to provide proof of concepts. The visions of ubiquitous networks with millions of nodes have yet to be realised (Gomez 1999).
1.14 Distributed Control

In recent years, industrial automation and control systems (Fig. 1.5) have been preferred to implement a Distributed Control System (DCS) instead of centralised systems, because of their advantage of greater flexibility over the whole operating range. Other benefits are low implementation costs, easy maintenance, configurability, scalability and modularity. Conventional centralised control is characterised by a central processing unit that communicates with the field devices (sensors, actuators, switches, valves, drives, etc.) with separate parallel point-to-point links. On the other hand, DCS interconnects devices with a single serial link. Since I/O points within the control systems are distributed and since the number of auxiliary components and equipments progressively increase, DCS architecture is seen to be appropriate. Each I/O point can be defined in terms of smart devices. Other operational benefits of adopting DCS schemes can be summarised. These include, sharing of the processing load for avoiding the bottle neck of a single centralised controller, replacement of complex point-to-point wiring harnesses with control networks to reduce weight and assembly costs, freedom to vary the number and type of control nodes on a particular application in order to easily modify its functionality, ability to individually configure and test segments (components) of the target application before they are combined, build and test each intelligent sub-units separately, and provisions for interfacing data exchanges between the runtime control system and other factory/business systems (e.g., management information, remote monitoring and control, etc.). DCS can be leveled into five layers of automation services. The bottom layer is called the component level, which includes the physical components such as intelligent devices (PC, industrial PC, PLC (Programmable Logic Controller), microprocessor, micro-controller etc.), and non-intelligent devices (sensors, actuators, switches, A/D, D/A, port, transceivers, communication media, etc.). The interface layer is similar to a MAC sub-layer of the link layer protocol. The third layer, called the process layer, includes application layer features. Since control systems do not transfer raw data through a physical media, an application layer has to exist. The top application layer defines the variables responsible for transferring data from one place to other when they are logically connected. This layer also generates object code from the source code by the use of resources and methods such as compilers and OLE/DDE, respectively. The final management layer manages the control design. There is a set of generic functions within the management layers, which are accountable for providing services for all aspects of control management. Typical management functions are installation, configuration, setting, resetting, monitoring, and operator interfacing and testing, among others.

1.14.1 DCS Realising Platform

Fieldbus is a technology for the realisation of DCS. This technology is being developed for most industrial automation and control applications. The leading fieldbuses with their characteristics can be seen in Mahalik (Mahalik 2003). The